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Children's Knowledge of Teen Quantities as Tens and Ones: Comparisons of Chinese, British, and American Kindergartners

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Three studies were conducted to examine the effects of individual differences and language differences on children's understanding of teen quantities ($11 \leq n \leq 19$) as counted cardinal tens and ones (embedded-ten cardinal understanding). At age 4, most Chinese children, using named-ten number words (e.g., 12 is said as "ten two"), did not show such understanding on a task in which y quantities were added to 10 quantities. At age 5, half the children of average or above intelligence who had high rote-counting sequences ($M = 90$) did show such understanding; those with lower rote-counting sequences did not. English-speaking 5-year-old children in England and in the United States, whose teen words obfuscate the tens and ones, showed no evidence of understanding teen quantities as cardinal tens and ones.

Asian students generally attain higher mathematics achievement than Western students (e.g., Geary, Bow-Thomas, Liu, & Siegler, 1996; Geary, Fan, & Bow-Thomas, 1992; Husen, 1967; Lapointe, Mead, & Philips, 1989; Stevenson et al., 1990; Stevenson, Lee, & Stigler, 1986; Stevenson & Stigler, 1992). This is true for some tasks even before school can have a great impact on mathematics learning. Asian students perform better than Western students in abstract counting to 100 (Bryant & Lines, 1992; Miller, Smith, Zhu, & Zhang, 1995; Miller & Stigler, 1987), in representing the place values of numbers with ten-structured blocks early in first grade (Miura, Kim, Chang, & Okamoto, 1988; Miura et al., 1994; Miura, Okamoto, Kim, Steere, & Fayol, 1993), and in mental addition in kindergarten (Geary, Bow-Thomas, Fan, & Siegler, 1993; Geary et al., 1996).

All of these early superiorities seem related to the regularity of number words in East Asian languages. Chinese, Japanese, and Korean (and some other languages) are regular for numbers between 10 and 100 in the same way that English is regular for the hundreds and the thousands: 5,900 is said as "five *thousand* nine *hundred*" in English and East Asian languages, but 59 also is said as "five *ten* nine" in the latter. In contrast, English uses a decade structure (e.g., twenty, thirty, forty, fifty), which obfuscates the meanings of these numbers as two-ten, three-ten, four-ten, and five-ten. In the English number words, learning the teens and using them in addition and subtraction are particularly difficult because of the irregularities (eleven, twelve) and the reversals (say four first in fourteen but write it second in 14; Geary et al., 1996; Miller et al., 1995; Miller & Zhu, 1991). In contrast, Fuson and Kwon (1991) found that most Korean children by the middle of first grade used addition and subtraction methods that involved thinking of teen numbers as a ten and some ones, and Geary et al. (1996) found similar results for Chinese children. Geary et al. (1996) found also that children in the United States rarely used such methods.

A crucial missing link in our understanding of how East Asian children come to use ten-structured addition and subtraction methods—and therefore how we might help English-speaking children learn these effective methods—is when and how East Asian children first understand that a counting word "ten x" is composed of a quantity of ten plus the quantity x, what we term *embedded-ten cardinal understanding.* An analogy in English is that a substantial number of urban U.S. first graders initially do not know that forty plus six is forty-six (Fuson & Smith, 1996). They count on six more from forty to find the sum of forty-six. After they have seen this relationship in some or many examples, the structure of the number words (and of the written numerals) as "first-addend word then second-addend word" helps them to generalize this understanding, so that they no longer have to count on each time (i.e., they have *embedded-decade cardinal understanding*). For embedded-ten or embedded-decade cardinal understanding, a child is required to shift from (a) the *sequence* meaning of the last counted word as just a rote sequence word and the *counting* meaning of that word as referring to the last object counted to (b) the *cardinal* meanings of "ten six" (or "forty six") as referring to all of the objects and of the embedded words "ten" and "six" (or "forty" and "six") as referring to groups of objects that are embedded within (that constitute) the total group of objects.

Embedded-ten cardinal understanding is itself embedded in the more general theoretical issue of the Whorf hypothesis (Whorf, 1956) that language affects thinking. We think of this issue as part of the more general issue of facilitations for directing thinking and attention and for expressing relationships. The presence of potential facilitations in the environ-

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ment is complex; they do not necessarily mean that everyone in that environment will be stimulated by the facilitations.

The regular ten-words in East Asian languages provide a facilitation for ten-structured addition and subtraction methods. These methods are more difficult for English-speaking children because they have an extra final translation step from "ten and five" to "fifteen." This sounds trivial to adults, but many English-speaking children experience considerable difficulty in constructing embedded-ten understanding for teen words and numerals. Kamii (1985) reported that substantial numbers even of U.S. fifth graders still do not possess embedded-ten cardinal understanding (they choose 1 rather than 10 objects as the meaning of the 1 in 16).

Although the number-word facilitations for embedded-ten understanding are available to East Asian children and not to English-speaking children, two other facilitations are available to both groups of children. Ten as a grouping is suggested both by our 10 fingers and by the structure of both types of counting words as having ten as the first counting stopping point.

We pursued when and how embedded-ten cardinal understanding is differentially facilitated by these cultural (number = word) and material object (finger) supports for East Asian and English-speaking children. We were interested in whether embedded-ten cardinal understanding is built gradually for some numbers only or comes all at once. We also examined two attributes that seemed likely to affect children's learning of embedded-ten cardinal understanding: IQ as a general measure of cognitive maturity (general learning potential) and the length of the counting sequence as a measure of specific learning in the number area and perhaps of the ease with which number words are produced, which would facilitate reflection on the content of the words.

We constructed the hidden-object addition task, to assess embedded-ten cardinal understanding: First, x items were put one by one into a box while they were counted out loud, then y items were put in as they were counted (beginning from 1), and then the child was asked how many items were in the box (the objects were no longer visible). For each $x + y$ problem, x was 4 or 10, and y was 2, 5, 7, or 9. Embedded-ten cardinal understanding could be used on the $10 + y$ items but not on the $4 + y$ items. If the child had full understanding, he or she would respond rapidly and correctly without any counting. Children's overt counting methods were recorded to examine differences in counting methods (e.g., counting on rather than counting all).

In our first study, the performance of Chinese children with different IQs and different mean lengths of counting sequence was followed longitudinally from age 4 to age 5. In the second study, the result that length of counting sequence affected embedded-ten cardinal understanding was followed up. Performance on the hidden-object addition task was compared for Chinese-speaking and English-speaking children with low and with high counting sequences. In the third study, the result that English-speaking children in England did not have embedded-ten cardinal understanding was followed up by examining the performance of English-speaking children in the United States.

Study 1

Method

Participants

The 36 participants in Study 1 were selected from a group of children participating in another longitudinal study. They all lived in Hong Kong and spoke only Chinese. Most of them came from middle-class families. The children were first assessed at the age of 4 years (M = 4 years 4 months, SD = 4.1 months), when they had just learned how to count to 10 in their preschool but before they had learned how to do sums (age 4). All of the children were assessed again 1 year later, when they were learning how to do very simple addition in their kindergarten, with sums of not more than 4 (age 5). Apart from the first warm-up trial (2 + 1), all other trials in the hidden-object addition task were far beyond the children's curriculum at either age.

Materials and Procedures

Before the study, the children had been assessed on the Stanford–Binet Intelligence Scale: Form L-M (3rd edition, Terman & Merrill, 1960) at the age of 3 years (mean IQ = 103, SD = 16, based on American norms). Children were tested individually on counting sequence and hidden-object addition at both age 4 and age 5.

Counting sequence. The procedure for the counting sequence task was taken from Miller and Stigler's (1987) study. The children were asked to count aloud as high as they could and were prompted at the beginning with "1, 2, 3" if necessary. If they stopped counting, they were prompted to continue by the question "What comes after x [the last number counted]?" If they still gave no response, they were further prompted by repeating the last three numbers counted in a rising intonation.

Hidden-object addition. Materials for this task included 20 one-inch square blocks, a box with a lid, and a stopwatch. There were nine $x + y$ trials in the task. In each trial, the experimenter asked the child to count with her while she was putting x number of blocks (i.e., the first addend) into the box. The procedure was repeated while a second set of blocks (i.e., the second addend, y) was put into the box. This was done so that the child could not count on from x while the y blocks were put in. The experimenter then closed the lid and asked, "First I put x blocks into the box, and then I put y more blocks in it. How many blocks altogether are in the box now?" Feedback was given by asking the child to count the total number of blocks in the box (the blocks were dumped out of the box onto the table, so that they could be counted).

The child's responses and observed solution strategies were recorded. Overt counting included counting that could be heard and lip movements of the counting words. Reaction times were recorded by starting the stopwatch at the end of the question and stopping it when the child began speaking. This method was accurate enough for our purposes of differentiating counting from more immediate responses because counting solutions took several seconds. To eliminate the possible distraction of minor details, we rounded off reaction times to the nearest second in the tables. Small variations in interviewer initiating and stopping the stopwatch across trials or across interviewers in the three studies thus are not an issue.

Of the nine trials, four were $4 + y$ trials, and four were $10 + y$ trials. The nine trials were as follows: 2 + 1, 4 + 2, 4 + 5, 4 + 7, 4 + 9, 10 + 2, 10 + 5, 10 + 7, and 10 + 9. The first warm-up trial was always 2 + 1. From the results of pilot studies, we found that 4-year-olds did not perform very well on this task and that it was difficult to maintain their interest and attention across all nine trials. Therefore, the 4-year-olds had only five trials: the 2 + 1 trial plus either the extreme *y* trials or the middle *y* trials (i.e., either 4 + 2, 4 + 9, 10 + 2, and 10 + 9 or 4 + 5, 4 + 7, 10 + 5, and 10 + 7). At age 5, the children received all nine trials. At both age 4 and age 5, half of the participants had 4 + *y* trials first, and half of them had 10 + *y* trials first.

Groups formed. On the basis of the distribution of counting sequence knowledge and IQ, the children were divided into three groups according to the following criteria. The low-CS–av-IQ children were those with correct counting sequences of less than 50 at age 5 (mean CS at age 4 = 14.7, *SD* = 6.0; mean CS at age 5 = 39.3; *SD* = 8.4; mean IQ = 93.2, *SD* = 8.3). The two high-CS groups were those who could count up to 50 or more. Children in the *high-CS–av-IQ* group had IQs lower than 105 (mean CS at age 4 = 35.9, *SD* = 24.7; mean CS at age 5 = 91.4, *SD* = 13.9; mean IQ = 93.8, *SD* = 7.7), whereas those in the high-CS–high-IQs group had IQs higher than 110 (mean CS at age 4 = 39.4, *SD* = 14.9; mean CS at age 5 = 87.5, *SD* = 19.5; mean IQ = 124.3, *SD* = 8.5). The high-CS–av-IQ group had significantly higher correct counting sequences than the low-CS–av-IQ group at age 4, $t(23) = 2.76, p < .05$, and age 5, $t(23) = 10.93, p < .001$, but the two groups did not differ significantly on IQ. The high-CS–high-IQ group had significantly higher IQs than did the high-CS–av-IQ group, $t(23) = 9.39, p < .001$, but these two groups did not differ significantly on correct counting sequences at age 4 or age 5. Group sample sizes are given in the Tables 1 and 2.

Criteria for embedded-ten cardinality understanding. Children who gave rapid (2 s or less) and accurate responses to all of the 10 + *y* trials without overt counting behavior and did not do so on all 4 + *y* trials were defined to be understanders of embedded-ten cardinality. To ensure that understanding rather than a rote pattern from the number words (i.e., just saying "10*y*") was being used, children were so classified only if they also did not give any responses of the form "4*y*."

Results and Discussion

Performance at Age 4

Two children understood embedded-ten cardinality, 1 in each of the high-counting-sequence groups. Only one of the 4 + *y* tasks done by both of these children was done correctly. Three other children in the two high-counting-sequence groups did both of the 10 + *y* tasks correctly, but the children seemed to be counting covertly or overtly, because five of these six trials had long reaction times, ranging from 4 to 27 s. All but one of the 4 + *y* tasks were done incorrectly by these children.

Many of the children at age 4 found the 2 + 1 trial solvable without the actual blocks but found the other trials to be difficult. In Table 1, we present the percentages of correct responses across trials in the hidden-object addition task for each group and the corresponding reaction times at age 4. From a Group × Problem analysis of variance (ANOVA) on the rates of correct responses, we found that the main effects of group, $F(2, 33) = 4.37, p < .05$, and problem, $F(1, 33) = 7.15, p < .05$, were significant, but the interaction effect was not. From the post hoc comparisons by the Tukey$_a$ test, we found that the two high-CS groups each performed significantly better than the low-CS–av-IQ group and that the two high-CS groups did not differ significantly in performance. Thus, high correct counting sequences are more related to initial success in addition than is high IQ.

None of the children showed any overt counting behavior in solving 4 + *y* problems correctly. However, 2 of the children counted all and another 2 children counted on overtly, to solve the 10 + *y* problems correctly.

Performance at Age 5

All except 1 child solved the practice problem (2 + 1) correctly without overt counting at age 5. This suggests that the children might have relied on memorized addition facts to do the 2 + 1 trial. At age 5, 3 children, all in the high-CS–high-IQ group, did all four 4 + *y* trials correctly and all four 10 + *y* trials correctly. No child got all 4 + *y* trials correct without getting all 10 + *y* trials correct, whereas 13 children got all 10 + *y* trials correct but not all 4 + *y* trials correct. Thus, children learned to add 10 + *y* correctly before 4 + *y*, McNemar's $\chi^2(1, N = 36) = 11.08$, $p < .01$. These 13 children were in the two high-CS groups.

There were 0, 7, and 7 embedded-ten cardinal understanders in the low-CS–av-IQ, high-CS–av-IQ, and the high-CS–high-IQ groups, respectively. The understanders had significantly higher scores than the nonunderstanders on IQ (M = 110 vs. 98), $t(34) = 2.28, p < .05$; correct counting sequence at age 4 (M = 43 vs. 22), $t(34) = 3.45, p < .01$; and correct counting sequence at age 5 (M = 92 vs. 63), $t(34) = 3.49, p = .001$. From these results, we suggest that cognitive maturity as well as a certain level of counting skills is required for embedded-ten cardinal understanding. However, when we did these analyses only on children in the two high-CS groups, the understanders and nonunderstand-

Table 1
Study 1: Age 4 Mean Percentage of Correct Responses and Mean Reaction Time for Each Group

	Low CS–av IQ		High CS–av IQ		High CS–high IQ		
Problems	C	RT	C	RT	C	RT	*M*
4 + *y*	0		14	3	18	2	11
10 + *y*	5	15	32	4	41	5	26
n	11		14		11		

Note. CS = counting sequence; av = average; C = mean percentage of correct responses across trials; RT = mean reaction time, rounded off to the nearest second, for correct responses; *M* = mean percentage of correct responses across groups.

ers did not differ significantly on IQ or correct counting sequences. Thus, a minimum level of correct counting sequence seems to be necessary but not sufficient for cardinal understanding.

We conducted a discriminant analysis, to ascertain whether IQ or length of correct counting sequence was more important in developing embedded-ten cardinal understanding. When we entered IQ and correct counting sequences at age 4 and age 5 as the independent variables, the discriminant function was significant in predicting the membership of embedded-ten cardinal understanding or nonunderstanding, $F(3, 32) = 5.70$, $p < .01$. The discriminant function coefficients for IQ and correct counting sequences at age 4 and age 5 were .28, .48, and .56 respectively. In other words, correct counting sequence at age 5 was the best discriminator of embedded-ten cardinal understanding and nonunderstanding, and IQ was the worst discriminator. The resulting pattern was consistent with the percentage of understanders in each group; that is, 0% in the low-CS–av-IQ group, 50% in the high-CS–av-IQ group, and 64% in the high-CS–high-IQ group.

We also conducted a two-way ANOVA on the rates of correct responses. Means for each group are given in Table 2. From the ANOVA results, we found that the main effects of group, $F(2, 33) = 16.53$, $p < .001$, and problem, $F(1, 33) = 26.35$, $p < .001$, were significant, but the interaction effect was not. As at age 4, the children performed significantly better on $10 + y$ problems than on $4 + y$ ones. On the basis of the post hoc comparisons by the Tukey_a test, we found that children in each of the two high-CS groups performed significantly better than those in the low-CS–av-IQ group and children in the high-CS–high-IQ group performed significantly better than those in the high-CS–av-IQ group.

Summary

Because all children could count through the teens but many, especially at age 4, did not use embedded-ten cardinality, the cardinal meaning of counting words followed rather than preceded learning the sequence itself. This is similar to the conclusions of Briars and Siegler (1984) concerning the relationship between children's counting and their understanding of counting principles: Understanding of some of the main principles followed rather than preceded accurate counting. Furthermore, both correct high counting sequences and cognitive maturity are related to the accuracy of adding and of using embedded-ten cardinality, but high correct counting sequences seem to be more strongly related to embedded-ten cardinality use than is cognitive maturity.

Study 2

Method

Participants

There were four groups of 5-year-olds in Study 2: two Chinese groups and two English groups. Children in the Chinese groups were selected from the sample in Study 1. Those in the English groups were selected from the English sample in another longitudinal Chinese–English study.

In the original longitudinal studies, by 5 years 3 months, the average correct counting sequence of the Chinese children was 80 ($SD = 32$), whereas it was only 45 ($SD = 33$) for the English children. Earlier researchers also have reported such learning differences (Miller & Stigler, 1987, for U.S. children, and Bryant & Lines, 1992, for British children), but IQ was not controlled in these earlier studies. In our sample, the mean IQ levels were similar: 105 for the Chinese children and 103 for the English children. Therefore, this cross-national difference is not due to some sample difference in IQ.

In Study 1, it was found that high counting skills are necessary for Chinese children to understand the cardinal meaning of number words and apply it in addition. Therefore, English groups were formed of high correct counting sequences (higher than 48) and of low correct counting sequences (with correct counting sequences less than 40). Chinese groups were selected to match them as close as possible on the group means of counting sequences and IQ levels as well as on the overall distribution. On the basis of these criteria, a total of 20 children in the high-counting-sequences groups (high-CS groups) and 16 in the low-counting-sequences groups (low-CS groups) were selected.

The two high-CS groups were matched quite well: The Chinese group did not differ significantly from the English group on age ($M = 64.6$ vs. 67.6 months, respectively), correct counting sequence ($M = 85$ vs. 92), or IQ ($M = 113$ vs. 114), all $ts(18) < 1.9$,

Table 2
Study 1: Age 5 Mean Percentage of Correct Responses, the Mean Reaction Time, and the Mean Percentage of Children Using Overt Counting Strategies for Each Group

	Low CS–av IQ			High CS–av IQ			High CS–high IQ			
Problem	C	RT	OC	C	RT	OC	C	RT	OC	*M*
4 + y	14	4	20	43	5	36	66	4	32	41
10+y	34	6	12	71	3	8	91	2	11	66
n		11			14			11		
Embedded-ten cardinal understanders										
n		0			7			7		
%		0			50			64		

Note. CS = counting sequence; av = average; C = mean percentage of correct responses across trials; RT = mean reaction time, rounded off to the nearest second, for correct responses; OC = mean percentage of children using overt counting strategies for correct responses.

all $ps > .07$. However, children in the English low-CS group were significantly older than those in the Chinese low-CS group (M = 68.8 vs 61.5 months), $t(14) = 5.09$, $p < .001$, although the two low-CS groups did not differ on correct counting sequence (M = 33 vs. 36) or on IQ (M = 99 vs. 91), all $ts(14) < 1.7$, all $ps > .11$. The Chinese and English high-CS groups were significantly higher than their corresponding low-CS groups on correct counting sequences, all $ts(16) > 4.6$, all $ps < .001$, and on IQs, all $ts(16) > 3.08$, all $ps < .01$, but they did not differ on age, all $ts(16) < 1.7$, all $ps > .12$.

Materials and Procedures

As reported in Study 1, the Chinese children's levels of intelligence had been assessed in another longitudinal study. Similarly, the English children had been assessed on the Stanford–Binet Intelligence Scale: Form L-M (3rd edition) at the age of 4 (mean IQ = 107, SD = 12, based on American norms) in the original longitudinal study. The English children were tested individually on counting sequence and hidden-object addition in exactly the same way as were the Chinese children at age 5 in Study 1, except that they were given the test in English. Chinese test instructions in Study 1 had been first translated into English and then back-translated, to ensure that the instructions were equivalent in the two languages.

Results and Discussion

All of the Chinese and English children did the 2 + 1 trial correctly without overt counting. Thus, by the age of 5, both Chinese and English children are able to add small numbers without great difficulty, no matter whether their counting sequences are high or low.

We present the results of the four groups in the hidden-object addition task in Table 3. Because the children performed differently for sums with large and small second addends, mean scores for 4 + (2 or 5), 4 + (7 or 9), 10 + (2 or 5), and 10 + (7 or 9) were computed and are shown in Table 3 and Figure 1. According to the criteria of ten-x cardinality understanders stated in Study 1, there were 7 understanders (70%) in the Chinese high-CS group but none in the other three groups. Again, no restating errors (4y) were found among the 4 + y trials for the Chinese understanders.

High-Counting Sequence Groups

A 2 (language: Chinese vs. English) × 2 (first addend: 4 vs. 10) × 2 (second addend: 2 or 5 vs. 7 or 9) ANOVA on the score of correct responses for the high-CS groups was computed. The language, first addend, and second addend main effects and the First Addend × Second Addend interaction effect were significant, all $Fs(1, 18) > 5.2$, all $ps < .05$. Although the two high-CS groups were matched on age, IQ, and counting sequence, children in the Chinese high-CS group did significantly better than those in the English high-CS group (M = 74% vs. 46%). Children in both groups did significantly better on 10+ y trials than on 4 + y trials (M = 69% vs. 51%) and on x + (2 or 5) trials than on x + (7 or 9) trials (M = 76% vs. 44%). From the post hoc comparisons by the Tukey$_a$ test, we found that children in the high-CS groups did not differ on 10 + y trials with small and large second addends. However, they did significantly better on 4 + y trials with small second addends than with large second addends (75% vs. 27%; q = .20, $p < .05$).

Even though children in both high-CS groups did 10 + y trials better than 4 + y trials, the solution strategies of the two groups were different. The children in the English high-CS group did the majority of trials for both 10 + y and 4 + y by counting (see Table 3). The children in the Chinese high-CS group also did the 4 + y trials with some counting (counted on most of the 4 + 7 and 4 + 9 trials), but they gave quick and accurate responses with no or little overt counting to most 10 + y trials. This suggests that the regular Chinese number-word pattern facilitates their calculation and memory of the addition facts for 10 + y sums, even when they do not have full embedded-ten cardinal under-

Table 3
Study 2: Age 5 Mean Percentage of Correct Responses, the Mean Reaction Time, and the Mean Percentage of Children Using Overt Counting Strategies for Each Group

	Chinese high CS			English high CS			Chinese low CS			English low CS		
Problems	C	RT	OC	C	RT	OC	C	RT	OC	C	RT	OC
4 + (2 or 5)	85	3	35	65	6	67	19	1	0	63	9	86
4 + (7 or 9)	40	6	92	15	17	67	6	8	0	13	18	100
10 + (2 or 5)	85	1	6	70	4	44	63	5	7	56	6	80
10 + (7 or 9)	85	1	6	35	7	70	31	10	25	19	11	67
n		10			10			8			8	
Embedded-ten cardinal understanders												
n		7			0			0			0	
%		70			0			0			0	

Note. CS = counting sequence; C = mean percentage of correct responses across trials; RT = mean reaction time, rounded off to the nearest second, for correct responses; OC = mean percentage of children using overt counting strategies for correct responses.

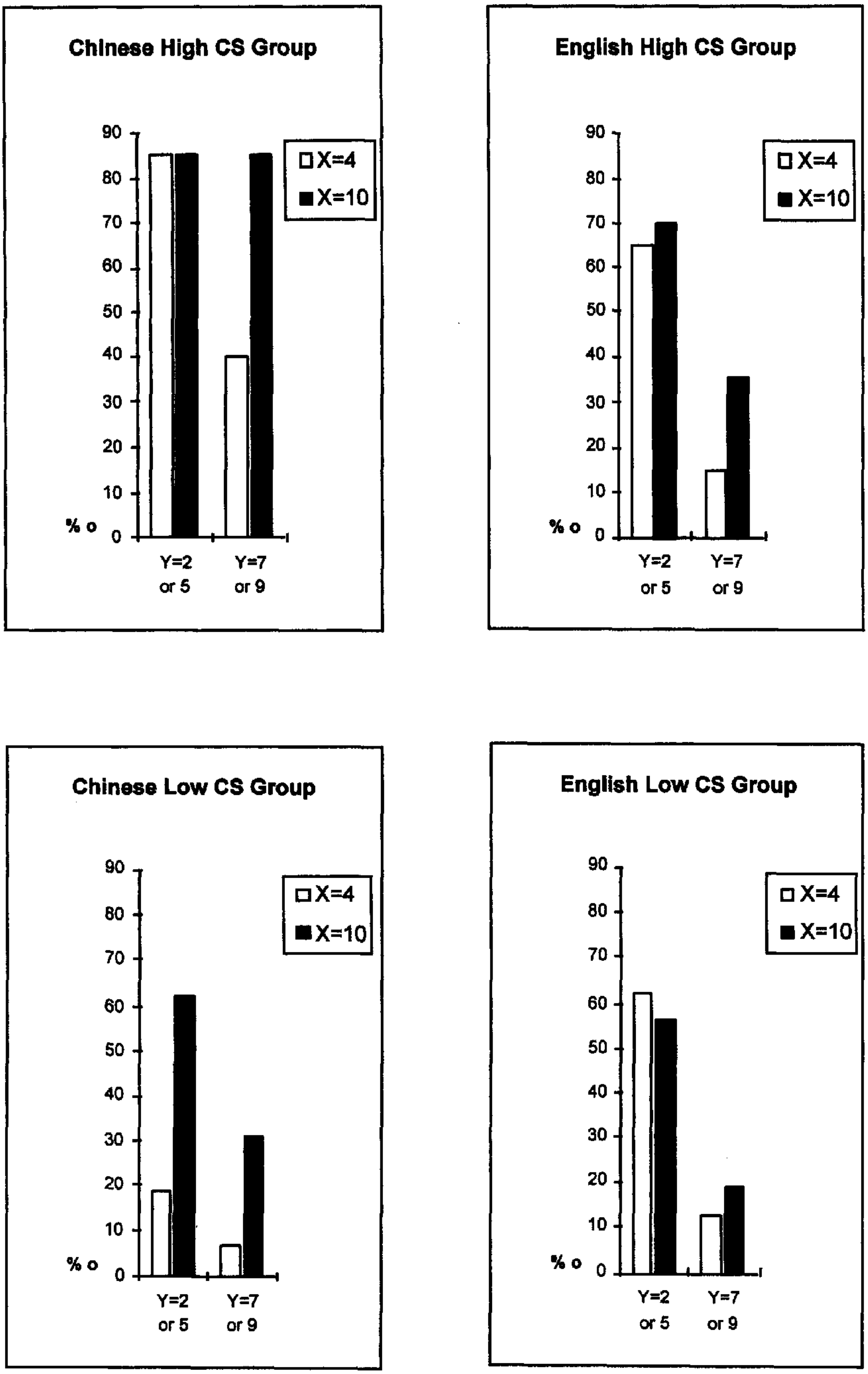

Figure 1. Percentages of correct responses across trials for sums $x + y$ on the hidden-object addition task for each group in Study 2. CS = counting sequence.

standing (immediate rapid correct responding on all $10 + y$ trials).

Low-Counting-Sequence Groups

A 2 (language: Chinese vs. English) × 2 (first addend: 4 vs. 10) × 2 (second addend: 2 or 5 vs. 7 or 9) ANOVA on the score of correct responses for the low-CS groups was computed. The first addend and second addend main effects and the Language × First Addend interaction effect were significant, all $Fs(1, 14) > 5.9$, all $ps < .05$. Overall, the children in the low-CS groups did significantly better on $10 + y$ trials than on $4 + y$ trials ($M = 42\%$ vs. 25%) and on $x +$ (2 or 5) trials than on $x +$ (7 or 9) trials ($M = 50\%$ vs. 17%). However, from the post hoc comparisons by the Tukey_a test, we found that children in the Chinese low-CS group performed significantly better on $10 + y$ trials than on $4 + y$ trials ($q = .291, p < .05$) but that those in the English low-CS group performed equally well on $10 + y$ and $4 + y$ trials. Children in the English low-CS group were, on average, 7 months older than those in the Chinese low-CS group. These English children made more correct responses on $4 + y$ trials (predominantly with much overt counting) than did the Chinese children. Thus, the older English children seemed to use counting strategies with small second addends with more success than did their Chinese counterparts. However, the children in the Chinese group surpassed those in the English group on the $10 + y$ trials. There was no embedded-ten cardinal understander in either of these two groups. Even though the children in the Chinese low-CS group did not understand embedded-ten cardinality consistently, they did find $10 + y$ sums more easily than $4 + y$ sums, and they did not count overtly to find most $10 + y$ sums. Thus, children may understand this gradually rather than all at once, at least children with shorter counting-word sequences.

A Good Match Is Hard to Find

One may question the matching of Chinese and English participants in this study. We understand that matching participants on one variable may produce groups of participants who are unmatched on some other relevant variables (e.g., Meehl, 1970; Stigler & Miller, 1993). We mentioned in the *Participants* section that Chinese children of comparable IQ tend to learn counting sequences earlier than English children. By matching both IQ and counting sequences of the two groups in this study, we might have selected English children with better education and learning motivation than their Chinese counterparts. Yet, the Chinese children in this study still showed greater embedded-ten cardinal understanding than did the English children. Therefore, the national differences in the development of embedded-ten cardinality seemed to be robust.

Study 3

Method

Participants

Twelve participants were selected to match the age and socioeconomic background of the English children. All were native speakers of American English. The children ranged in age from 60 to 70 months, with an average of 66 months ($SD = 3.2$). The range of accurate rote-counting sequence was 29 to 200, with a mean of 69.8 ($SD = 50$).

Materials and Procedures

The children were tested individually on the hidden-object addition task and then on the counting sequence task, in exactly the same way as were the English children in Study 2.

Results and Discussion

All of the children did the 2 + 1 warm-up trial correctly without overt counting. Children receiving the $4 + y$ trials first increased their use of overt verbal or finger counting (see Table 4). Children receiving the $10 + y$ trials first did all trials with no overt counting and rapidly gave correct answers. In contrast, of the 6 children receiving the $4 + y$ trials first, 4 overtly counted verbally or with fingers on 1 or more trials. These 4 children counted on 8 of the $4 + y$ trials (4 of which were correct) and on 11 of the $10 + y$ trials (5 of which were correct).

Rote-counting skill (mean counting sequence above or below 50) did not affect performance, except that all children with a counting sequence above 50 did the 4 + 2 trial accurately whereas only half the children with a counting sequence between 29 and 49 did so. Thus, as with the Chinese children (although in a different fashion), knowledge of the counting sequence considerably exceeds addition performance. Children learn a very long sequence before they can do even simple addition of much smaller numbers when objects are hidden.

Table 4
Study 3: Mean Percentage of Correct Responses, Mean Reactions Times, and Mean Percentage of Overt Counting for Children in the United States by Order of First Addend

	4 + y items first			10 + y items first			Total		
Problems	C	RT	OC	C	RT	OC	C	RT	OC
4 + (2 or 5)	67	9	38	50	2	0	59	6	21
4 + (7 or 9)	9	25	100	0			4	25	100
10 + (2 or 5)	67	10	38	25	3[a]	0	46	8	27
10 + (7 or 9)	17	15	100	9	2	0	13	10	67
n		6			6			12	

Note. C = mean percentage of correct responses across trials; RT = mean reaction time, rounded off to the nearest second for correct responses; OC = mean percentage of children using overt counting strategies for correct responses.
[a]One child reported using the wall clock for 10 + 2 and had a reaction time of 14 s; this reaction time was omitted as an outlier of time and method.

There was no evidence of embedded-ten cardinal understanding or of knowledge of embedded-ten memorized facts. No child met the criterion for embedded-ten cardinal understander; the only child to get all of the $10 + y$ trials correct counted with fingers for three of those four trials.

Performance was affected primarily by the size of the second number added. Children did well on the trials in which 2 objects were added, counting increased performance on the trials in which 5 objects were added, and the trials with 7 or 9 objects added were difficult and were rarely solved correctly. Whether the first addend was 4 or 10 did not affect the correctness of answers very much. Children did not use the feedback of counting at the end of each trial, to suggest counting using substitute objects (i.e., counting did not increase over trials), and did not use any pattern they might have understood in the ten words (e.g., seventeen is ten and seven).

General Discussion

In summary, Chinese children surpass their English and American counterparts not only in rote counting and place value numeration, as found in previous studies, but also in embedded-ten cardinal understanding and in applying this knowledge to solving simple addition problems. Furthermore, the earlier learning of the rote-counting sequence, as found in earlier studies, was found here not to depend on IQ. Most Chinese 4-year-olds have not yet developed general embedded-ten cardinal understanding. Many, but not all, 5-year-olds with an average or above level of intelligence and a well-automatized counting sequence (near 100) understand embedded-ten cardinality and apply this knowledge to solving addition problems.

Different researchers have suggested that either cultural factors or language factors account for the national differences in mathematics achievement (e.g., Geary et al., 1993; Stevenson, Lee, Chen, et al., 1990; Stevenson, Lee, & Stigler, 1986; Stevenson & Stigler, 1992). These both might be important, however. Yang and Cobb (1995) found that the initial arithmetical learning activities in which Chinese children engaged at home and in school supported the development of composite multiunit numerical conceptions (e.g., the emphasis of a decade as a counting unit and the use of the up-over-10, down-over-10, and subtract-from-10 methods in solving simple addition and subtraction problems). Furthermore, Chinese mothers and teachers seemed to believe that it is natural for Chinese children to develop the concept that numbers are composed of tens and ones early, whereas the American children were initially encouraged to construct unitary number concepts based on counting by ones. Therefore, apart from the direct influence of the number-word regularities on Chinese children's conceptual development of numbers, the influence also may be mediated by Chinese adults' beliefs about children's arithmetical development and resultant culturally supported learning activities at home and in school.

School training was unlikely in the present studies to be a contributing factor for the Chinese superiority in embedded-ten cardinal understanding and in solving $10 + y$ problems. The Chinese children in Study 1 and Study 2 learned how to count in school beginning at the age of 3. Rote counting was taught in class by asking children to follow teachers' recitals and was practiced during many school activities (e.g., when going to the toilet or when lining up). The counting sequence was lengthened gradually to 100 by the age of 5. However, these counting activities did not attach to any objects andthus had no cardinal meanings, so embedded-ten cardinal meanings were not supported by reported school activities. By the age of 5, the Chinese children had learned how to do simple addition with sums less than 5 in school. Thus, apart from the $2 + 1$ warm-up trial, all other problems had not been taught in school.

Arithmetical training at home was not examined in the present studies. Because the Chinese participants in Study 1 and Study 2 came from the same kindergarten, school factors were less varied than home factors. Whether the Chinese parents of embedded-ten cardinal understanders support the development of this understanding at home is of interest for future research. How they capitalize on the regular-tens number words could be a model for use in schools for those Chinese-speaking children who are not yet embedded-ten cardinal understanders, as well as for methods that might extend to English-speaking children.

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